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Vegetation Responses to Grazing, Rainfall, Site Condition, and Mesquite Control on Semidesert Range

Dwight R. Cable and
S. Clark Martin

July 1975



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Abstract

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Changes in herbage production, basal intercept, and grazing use of perennial grasses, herbage production of annual grasses, and crown intercept of shrubs and trees were related to changes in rainfall, presence or absence of velvet mesquite, and to differences in soil, topography, and salting. Over a 10-yr period, mesquite control increased perennial grass production 52 percent. Perennial grass production was highly dependent on both last summer's and this summer's rainfall, indicating that 2 yrs are required for recovery from a 1-yr drought. Too heavy use greatly restricted production in wet years that followed dry years. Because of the strong relationship between rainfall and grass production, stocking rates could be estimated as accurately from rainfall as from grass production.

Keywords: Semidesert range, mesquite control, grass production, rainfall effects, grazing effects, site conditions.

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Vegetation Responses to Grazing, Rainfall, Site Condition,
and Mesquite Control on Semidesert Range L J

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RESEARCH HIGHLIGHTS

Herbage production, basal intercept, and grazing use by cattle of perennial grasses were measured annually from 1957 to 1966 at 20 locations in each of four pastures at the upper edge of the semidesert grass-shrub type on the Santa Rita Experimental Range. Mesquite trees were killed on two of the pastures prior to the start of the study. Herbage production of annual grasses and crown intercept of shrubs and trees were also measured annually. Changes in these variables were related to changes in rainfall, presence or absence of velvet mesquite, and to differences in soil, topography, and salting. The major findings of this study, summarized in the following paragraphs deal largely with the ecological relations among the vegetation, climate, and grazing treatments. Some have strong management implications.

1. Effect of mesquite control on perennial grass production. Perennial grass production for the 10-year study period averaged between 352 and 524 lb/acre on the four pastures. At the time the mesquite was controlled (1954-57), perennial grass production was in equilibrium with the invasion stand of mesquite. The influence of mesquite on perennial grass production became apparent as the grass stand responded over time to the release from mesquite competition. The grass stand had readjusted to the additional moisture available as the result of mesquite control by about 1963. By that time, perennial grass production on the mesquite-killed (M-K) pastures had increased 168 lb/acre (52 percent) relative to that on the mesquite-alive (M-A) pastures.

2. Effects of summer rainfall on perennial grass production. Perennial grass production changed greatly from year to year due to changing precipitation. The precipitation components having the greatest effect on year-to-year changes were: (1) rainfall for August of the current summer, and (2) the interaction (product) of rainfall for the current August

times rainfall for June-September of the previous summer. The most influential component was the interaction product, which accounted for from 63.5 to 91.0 percent of the year-to-year variation in total perennial grass production. This means that the grass-producing effectiveness of a given amount of rainfall during a given summer depends on the amount of rainfall received the previous summer.

3. Practical implications of rainfall effects. The above results have strong management implications. Summer rainfall gives the range manager some advance indication of what to expect in the way of grass production, and rainfall is much easier to measure than is grass production. The fact that rainfall in two successive summers is involved in the current summer's perennial grass production means that low rainfall in one summer not only reduces production during the current summer but reduces the prospects for the next summer as well. Management decisions should be made with the thought in mind that it takes at least 2 years to recover from a 1-year drought.

4. Effects of degree of use on perennial grass production. Different levels of use during the 10-year study period significantly affected perennial grass production. The specific effect of heavy use (10-year mean use between 52 and 59 percent) was to greatly restrict gains in production in wet years following a dry year. Gains were highest on transects with the lowest mean use (21 to 28 percent) and decreased with each successively higher use level. Two or three favorable years were required for recovery of heavily used transects following a single dry year. One major species, Arizona cottontop, reacted differently from the other species, in that successively higher levels of use stimulated rather than lowered production in wet years. Cottontop is able to tolerate levels of use that are quite damaging to most other species.

5. Results of alternate-year summer deferment. Alternate-year summer deferment did not improve perennial grass production. This does not mean that these ranges may not benefit from periodic rest. Rather, the rest given by this schedule simply did not adequately satisfy the physiological needs of the grasses. Other studies on the Santa Rita also show that alternate-year summer rest does not provide enough recovery time between grazing periods.

6. Influence of slope on perennial grass species. Most perennial grasses exhibited slope preferences. Of the 14 most productive species, six preferred slopes less than 10 percent, four preferred slopes over 30 percent, and four showed no particular preference. Of the five major producers, Arizona cottontop showed a strong preference for flatter slopes, tall three-awns a weak preference for flatter slopes, side-oats grama a weak preference for steeper slopes, and black and slender gramas little or no preference.

7. Soil-species association for perennial grasses. Two soil types predominated on the more moderate slopes on the study pastures: Whitehouse with clayey subsoils, and Comora with gravelly subsoils. The steeper slopes were characterized by shallow, rocky Coronado soils. Tall threeawns and slender grama grew almost equally well on all three soils, but with a slight tendency to decreasing preference from Comora to Whitehouse to Coronado. Arizona cottontop was well adapted to the Comora and Whitehouse soils, but poorly to the Coronado. Side-oats grama was particularly well adapted on the Coronado soils, moderately on Comora and Whitehouse. Black grama showed no particular preference, but grew almost equally well on all soils.

8. Effects of rainfall on annual grass production. Annual grass production fluctuated markedly from year to year. Changes in June-through-August rainfall of the current year accounted for from 78 to 91 percent of year-to-year changes. The general levels around which these fluctuations occurred differed from place to place, however, depending largely on the amounts of perennial grasses and mesquite present at the particular site. Perennial species, with their established root systems, have a strong competitive advantage over annuals in the extraction of available soil moisture. The

annual grasses thrive only when more moisture is available than the perennial species can use.

9. Competition between annual and perennial grasses. Annual grass production was highest, relative to perennial grass production, on the most favorable sites; as environmental conditions became less favorable, competition between perennial and annual grasses increased and annual grass production decreased relative to perennial grass. On optimum sites for grass growth and with no mesquite competition, annual grass production varied from zero where perennial grass production was 940 lb/acre to about 500 lb/acre where perennial grass production was 275 lb/acre (increasing 75 lb/acre for each decrease of 100 lb/acre in perennial grass production).

10. Mesquite and annual grass production. Yields of annual grass were three times as great on mesquite-killed as on mesquite-alive range. However, effects of mesquite on annual grass production were so interwoven with other site factors (soil, slope, other competing vegetation) that annual grass production was essentially zero at some locations at all levels of mesquite density. Maximum annual grass production was limited by the degree of mesquite cover, however, where mesquite crown cover exceeded 10 or 12 percent. Annual grass production decreased about 50 lb/acre for each 10 percent increase in mesquite crown cover, and reached zero at about 40 percent mesquite crown cover. Ten-year mean annual grass production was 149 and 208 lb/acre on the two M-K pastures and 26 and 87 lb/acre on the two M-A pastures.

11. Changes in mesquite cover. Mesquite showed little recovery on the M-K pastures during the 10-year study period. Crown cover averaged less than 0.5 percent on both pastures at the end of the period. On the two M-A pastures, crown cover increased from 11.04 to 13.31 percent on one pasture and from 7.17 to 12.67 percent on the other.

12. Relation of utilization to stocking. Ten-year mean perennial grass utilization for the four pastures ranged from about 30 to 50 percent. Use of perennial grass herbage on individual transects averaged between 19 and 72 percent. Forage use was influenced by the amount of forage available per animal and by

animal preference for different grass species. Relative use of any given crop of forage varies, of course, with rate of stocking. In this study, however, stocking rates were adjusted each fall to utilize about 40 percent of the perennial grass available for grazing, and measured differences in use from year to year were not significantly related to animal numbers.

13. Species preferences of cattle. Cattle preferences for individual species varied widely. For 18 species of record, average use ranged from 6 to 62 percent. Levels of use were more or less independent of the abundance or productiveness of the various species. However, the amounts of each species available, of course, limited actual consumption. Typically, the preferred species were grazed first and most heavily; use of less preferred species increased as the overall level of use increased.

14. Apparent cattle diet composition. Production and utilization records for individual species provided a basis for approximating the cattle diet:

Major species	Mean percent use	Percent of production	Percent of diet
Slender grama	31	19.2	17.5
Arizona cottontop	57	13.6	22.4
Side-oats grama	29	13.0	11.2
Tall threeawns	38	12.6	14.2
Black grama	12	11.8	7.1

Of the five major producers, cottontop contributed much more to the diet than its proportion of total production. Black grama contributed much less than its production would indicate. The other three contributed to the diet roughly in proportion to their productivity.

15. Importance of less palatable species. On a properly managed range, much of the herbage of the least-preferred species will be ungrazed at the end of the grazing year (especially following a wet summer of high production). This unused dry herbage, even though of relatively low nutrient content, constitutes a reserve of forage that may be used later.

16. Influence of slope and distance to water. Cattle prefer to graze close to water on flat land. As distance from water increases and

slopes become steeper, use typically declines. However, other factors such as local surface relief features or unusual concentrations of vegetation can completely override slope and distance effects, particularly where slopes are less than 10 percent and distances from water less than 1 mile. Under maximum effects of slope and distance, percent use decreased about 5 percent for each increase of 10 percent in slope, and decreased 3 to 3.5 percent for each increase of 0.1 mile from water. Under such conditions, either slope or distance can account for as much as 50 percent of the variability in use within a pasture. Light grazing of steep slopes in this study was only partly the result of lazy cows. The steeper slopes generally were occupied by less palatable species. Moreover, the steep slopes probably were not grazed until the forage was mature and well past its peak palatability.

17. Effect of salt on utilization. The placement of salt grounds can markedly alter utilization patterns and promote more even utilization of the perennial grass crop. Establishment of a new salt ground 1.5 miles from water midway in the study increased use within 0.5 mile of the new salt ground. Use averaged about 9 percent before establishment of the new salt ground and 25 percent afterward. Meanwhile, use in the remainder of the pasture increased from 38 percent to 41 percent.

18. Estimating stocking rates. Stocking rates were determined annually from a formula involving available annual and perennial grass, and past stocking adjusted to 40 percent use. However, because of the strong relationship between perennial grass production and rainfall (interaction product—item 2 of Research Highlights), estimating equations developed from records of rainfall, stocking, and use give stocking rate estimates that appear even better than those based on grass production, stocking, and use.

19. Economic evaluation of mesquite control. Estimates indicate that increased stocking made possible by increased grass production would recover mesquite control costs within about 6 years. Increased productivity can be expected to continue for 15 to 20 years after mesquite has been controlled.

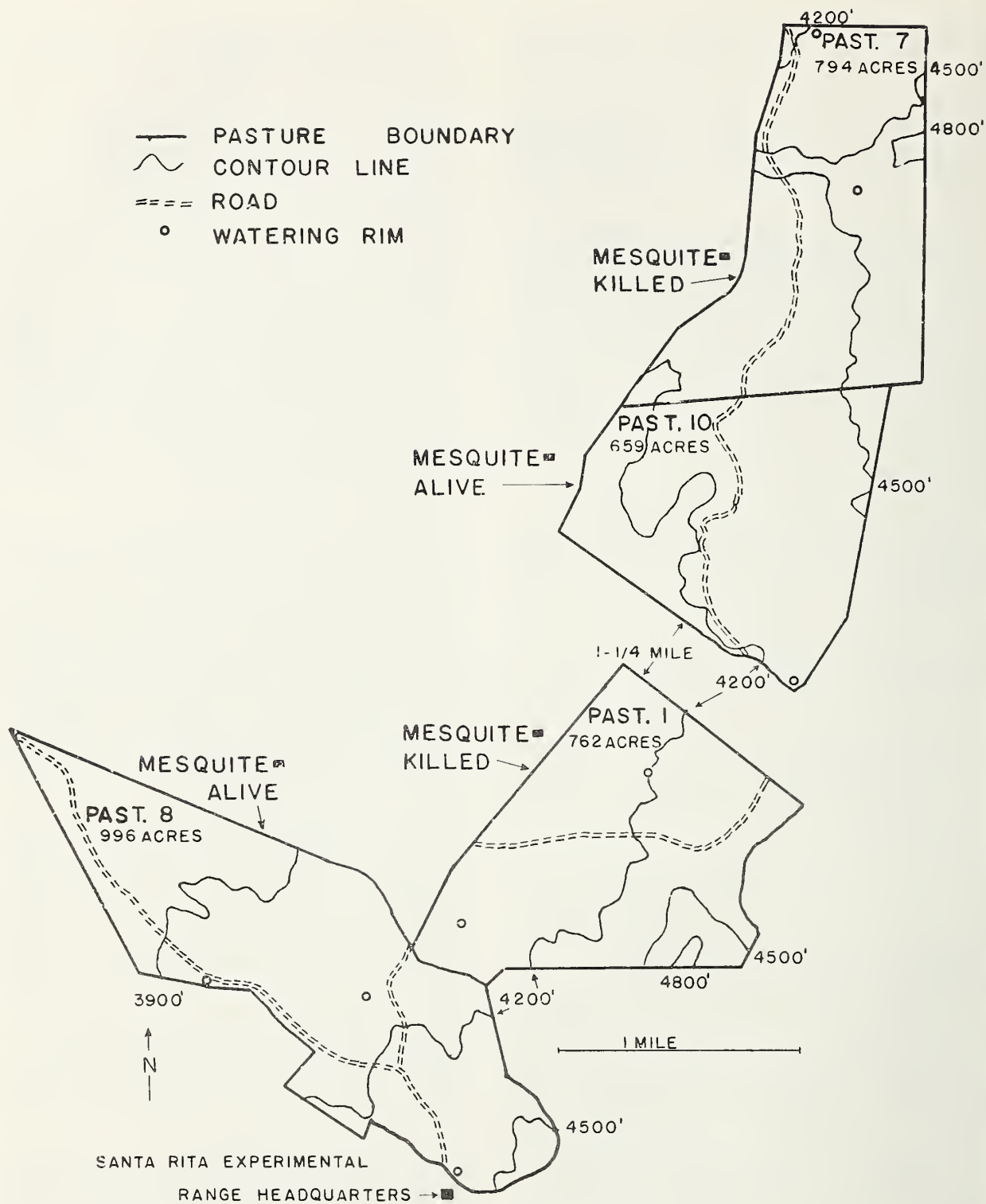


Figure 1.—Arrangement of pastures used in the study.

Vegetation Responses to Grazing, Rainfall, Site Condition, and Mesquite Control on Semidesert Range

Dwight R. Cable and S. Clark Martin

INTRODUCTION

Management of Southwestern rangelands must serve various purposes, among which are the raising of livestock, the production of wildlife, provision of open-space recreation opportunities for city dwellers, and the protection of the soil. These uses of rangelands all require (1) the maintenance of a vegetation cover on the land, (2) an understanding of the particular types of vegetation best adapted to particular uses, and (3) an understanding of the effects of particular uses on the vegetation.

This Paper discusses changes in vegetation during a 10-year period (1957 to 1966) on semidesert rangelands on the Santa Rita Experimental Range near Tucson, Arizona, as affected by climatic factors, cattle grazing, and the control of velvet mesquite.² Some preliminary results were discussed in an earlier paper (Cable and Martin 1964).

THE STUDY PASTURES

The four pastures used in this study were located on a narrow band of foothills along the base of the Santa Rita Mountains between elevations of 3,700 and 4,800 feet (fig. 1). Soils varied widely, from relatively deep coarse sandy loams on the flatter slopes (some with clayey subsoils), to shallow stony soils on the steeper slopes. Major soil series were Whitehouse, Comora, Coronado, and Tumacacori.

Average annual (October to September) precipitation varied among the four pastures from 14.7 to 18.6 inches from 1954 to 1966. Daily maximum temperatures during the summer were usually in the nineties, although a few days of 100+°F occurred most summers. Summer minimums generally were in the sixties. In winter, maximums in the high fifties or low

sixties were typical, with minimums in the high thirties, although lows in the twenties, or occasionally below, were sometimes recorded.

Vegetation Cover

In the early years of this century the vegetation cover on these pastures was characterized as grassland, as evidenced by photographs and reports of early workers. In the ensuing 40 years, velvet mesquite rapidly invaded, with continued more gradual increases until 1954-57 when the mesquite in two of the pastures was killed. Prior to the start of this study, mesquite densities averaged from about 80 to 180 per acre, although one 0.5-acre plot contained 775 mesquites per acre. Perennial grass understory in 1957 varied from essentially none under the few very dense stands of mesquite to fair to good over most of the acreage (fig.2). Vegetation characteristics of the study pastures in 1957 were as follows:



Figure 2.—Representative area in pasture 10, supporting ocotillo and velvet mesquite, with the Santa Rita Mountains in the background. The grasses are mainly black grama and Arizona cattantop.

² Nomenclature follows Kearney and Peebles (1951). Common and botanical names of plants mentioned are listed at the end of this paper.

	Mesquite- killed	Mesquite- alive
Perennial grass basal intercept (percent)	0.82	1.09
Perennial grass herbage production (lb/acre)	221	299
Annual grass production (lb/acre)	179	38
Shrub crown intercept (percent)	9.58	12.16
Mesquite crown intercept (percent)	0.19	3.76
Mesquite density (trees/acre)	9	128

The major perennial grasses, in order of decreasing abundance, were: slender grama, side-oats grama, tall threeawns, Arizona cotton-top, black grama, and sprucetop grama. Predominant annual grasses were sixweeks three-awn and needle grama. The most abundant shrubs, other than mesquite, were false-mesquite, velvetpod mimosa, and catclaw acacia.

Grazing History

The four pastures had been grazed yearlong by cow-calf herds since 1915. From 1915 to 1925 the stocking rates averaged from 32 to 34 head per section. Declining productivity showed, however, that such rates were too high, and numbers were reduced more or less progressively until around 1940. During the 16-year period, 1941-56, immediately before this study began, stocking rates averaged 16, 13, 14, and 15 animal units per section in pastures 1, 7, 8, and 10, respectively. Utilization of perennial grasses during this period averaged 60, 58, 59, and 47 percent in the four pastures.

METHODS

Mesquite Control

Mesquites in pastures 1 and 7 were killed between 1954 and 1957 by spraying the stem bases with diesel oil (Reynolds and Tschirley 1957). A followup treatment in 1960 killed new plants and the few plants missed in the original treatment. Costs for each treatment averaged

about 5 cents per tree, although labor cost was proportionately higher for the followup treatment. The original treatment cost was split equally between labor and diesel oil. The follow-up treatment cost was divided 80 percent for labor and 20 percent for oil. More diesel oil was required in the original treatment (1.5 pints/tree) than in the followup treatment (0.75 pint) because most of the mesquites treated in the followup were small.

Grazing Management

Two changes in management were instituted in the fall of 1957 at the start of the study period: (1) the utilization objective was lowered to 40 percent, and (2) summer deferment (July to September) in alternate years was started. Deferment of summer grazing was started in one mesquite-killed (M-K) and one mesquite-alive (M-A) pasture in 1958 and in the other pastures in 1959.

Stocking rates necessary to obtain 40 percent use of perennial grasses were estimated separately for each pasture in October each year, based on measurements of annual and perennial grass produced during the previous summer. Multiple regression equations, to determine these stocking rates, were based on past records of annual and perennial grass yields, actual stocking, and utilization of perennial grasses. They were of the form:

$$S = b_1A + b_2P + a$$

where

S=estimated stocking for 40 percent utilization
A=current-year air-dry annual grass yield
(lb/acre)

P=current-year air-dry perennial grass yield
(lb/acre)

b_1 , b_2 , and a =constants derived from the regression computations involving prior production, stocking, and utilization data.

The procedure used in developing this equation was similar to that presented by Reid et al. (1963). A separate equation was developed for each pasture and recomputed annually to include data for the year immediately past.

Vegetation Measurements

Vegetation records were obtained at 20 randomly selected locations in each pasture. At each sampling location, a 100-foot line transect was established along which intercepts of vegetation were measured annually in late summer (except in 1960), by the method of Canfield (1942). A forage production transect, established adjacent to each intercept transect, was used for yearly early-fall measurement of annual and perennial grass production by the double-sampling technique of Wilm et al. (1944). At each transect, estimates were made on five permanent 9.6- by 1-ft plots, and on one temporary plot from which herbage was clipped and weighed. Utilization of perennial grasses was measured by the ungrazed-plant method (Roach 1950) in June each year on a 100- by 200-ft plot centered over the intercept transect. Crown diameters of all mesquites on the 100- by 200-ft plots were measured in 1957 and 1967, at the start and end of the study.

Other Records

Precipitation data were obtained from one standard rain gage in each of three pastures and two gages in the fourth pasture. Storm totals were obtained at two gages, and were interpolated from nearby recording gages for the other three gages. Soils information was available from two detailed surveys (Youngs et al. 1936).³

RESULTS AND DISCUSSION

Information pertaining to individual physical and biological attributes are presented first, either for the period of record (1954-66) or for the study period (1957-66), and then their interrelationships are discussed.

Analysis of Precipitation Records

The effectiveness of precipitation in producing grass herbage varies greatly with season

³ Clemmons, Stan, and L.D. Wheeler. 1970. *Soils report, Santa Rita Experimental Range, Coronado National Forest. n.p. (Typed report by the Southwestern Region, USDA Forest Service, Albuquerque, N.M.; copy on file at Rocky Mountain Station's Research Work Unit, Tucson, Arizona.)*

of the year, and to a lesser extent with other factors such as size, spacing, and intensity of storms. Because of the two distinct rainy periods characteristic of southern Arizona, and the fact that growth of all our grass and shrub species depends on one or both of these rainy periods, annual precipitation for the four study pastures has been divided into four periods: the two rainy periods (June-September, and December-April) and the two intervening drier periods (October-November, and May). June is normally a very dry month too, but in about 1 year in 6 or 7, the first major storm of the summer rainy season occurs during the last 10 days of June; this rainfall is important in the production of herbage for that summer.

During the 13-year period from 1953-54 to 1965-66, annual precipitation for the four pastures averaged 17.07 inches (table 1). About 62 percent of the annual precipitation fell during June-September, about 10 percent in October-November, about 27 percent December-April, and less than 1 percent in May.

Table 1.--Four-pasture average of seasonal precipitation, by grass year (October 1 - September 30) for period of record (1954-66) and study period (1957-66)

Grass year	Oct.- Nov.	Dec.- Apr.	May	June- Sept.	Total
- - - - - Inches - - - - -					
1953-54	0.21	4.13	0.69	11.31	16.34
1954-55	.55	3.16	0	16.25	19.96
1955-56	.47	3.53	0	5.12	9.12
- - - - -					
1956-57	.49	4.51	.28	8.70	13.98
1957-58	2.71	6.09	.02	15.07	23.89
1958-59	2.45	1.20	0	12.17	15.82
1959-60	2.67	5.86	0	6.10	14.63
1960-61	1.67	3.41	0	12.94	18.02
1961-62	3.69	5.97	0	5.42	15.08
1962-63	.76	5.01	.04	8.64	14.45
1963-64	4.01	2.75	.03	14.65	21.44
1964-65	2.13	3.81	.15	8.97	15.06
1965-66	.98	11.48	.04	11.64	24.14
- - - - -					
Mean	1.75	4.68	.10	10.54	17.07
- - - - - Percent - - - - -					
	10.25	27.42	.59	61.74	100.00

Rainfall in September is a part of summer rainfall; however, only that rainfall received during the June-August period is intimately associated with perennial grass production. Al-

though June-August precipitation varies widely from year to year (up to four times as much in one year as the next), a significant downward trend is evident in June-August rainfall during the period of record (fig. 3), averaging 0.38 inch decrease per year for the four pastures.

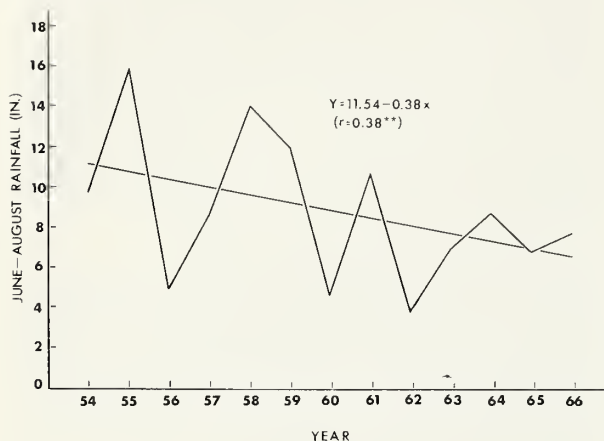


Figure 3.—Trends in June-August rainfall, showing average yearly rainfall for the four pastures and average trend.

Perennial Grass Production

Average perennial grass production for the 13-year period of record (1954 to 1966) varied from 314 lb/acre in pasture 7 to 465 lb/acre in pasture 1 (table 2). For the 10-year study period (1957-66), production varied from 352 to 524 lb/acre. Production in the highest year of the 10-year period was three to five times as high as in the lowest year.

Three-year moving averages of perennial grass production, computed for the 1957-66 study period for the two pairs of pastures (pastures 1 and 7—mesquite-killed; pastures 8 and 10—mesquite-alive), show that production on the M-K pastures increased 52.3 percent relative to that on the M-A pastures between 1957-59 and 1964-66 (fig. 4). Production on the M-K pastures held more or less steady, despite a 24 percent decrease in summer (June-August) rainfall, while production in the M-A pastures decreased somewhat more than did summer rainfall.

Effect of Deferment

Alternate-year summer deferment had no apparent beneficial effect on perennial grass

Table 2.—Perennial grass production, with representative standard errors, for period of record (1954-66) and study period (1957-66)

Year	Pasture 1	Pasture 7	Pasture 8	Pasture 10
----- Lb/acre -----				
1954	217	193	251	199
1955	389	300	242	417
1956	197	69	144	140
1957	282 ± 42	160 ± 19	241 ± 33	357 ± 27
1958	605	368	645	631
1959	773	568	742	857
1960	357	183	197	358
1961	744	575	480	559
1962	368 ± 28	116 ± 10	289 ± 42	169 ± 16
1963	475	288	353	223
1964	484	233	364	227
1965	584 ± 57	551 ± 39	393 ± 33	486 ± 32
1966	573	483	453	483
Mean:				
13-yr*	465	314	369	393
1957-66*	524 ± 13	352 ± 14	416 ± 11	435 ± 9

*Differences between pasture means significant at $P = < 0.05$.

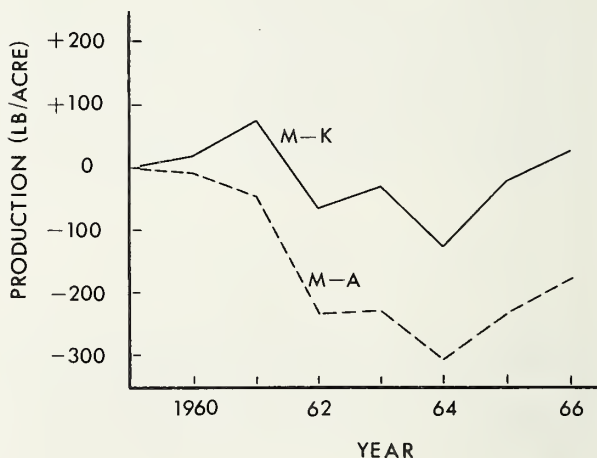


Figure 4.—Cumulative change in perennial grass production on mesquite-killed (M-K) and mesquite-alive (M-A) pastures (3-year moving averages ending on the indicated year).

production. This conclusion is based on a comparison of production on the two M-A pastures with that of a similar mesquite-infested pasture that not only was grazed yearlong, but was grazed more heavily during summer than winter in alternate years. Changes in perennial grass

production between the first 3 years and the last 3 years in this pasture were similar to those on the M-A pastures: 25.2 percent less production in the last 3 years, compared to 30.7 percent less on the M-A pastures. No similar comparison can be made for the M-K pastures because of the lack of an M-K pasture grazed yearlong.

The fact that summer deferment in alternate years did not improve perennial grass production on the M-A pastures does not mean that these ranges do not need, or will not benefit from, periodic rest. It does mean that resting at this season and frequency did not result in significant benefits. Other data collected on the Santa Rita indicate that other resting schedules do result in improved perennial grass density and production (Martin 1973). It is also possible that perennial grass production on the M-A pastures is at near-optimum levels for mesquite-infested ranges.

Composition of Perennial Grass Herbage

Of the 31 perennial grass species observed, from 15 to 22 were recorded in each pasture.

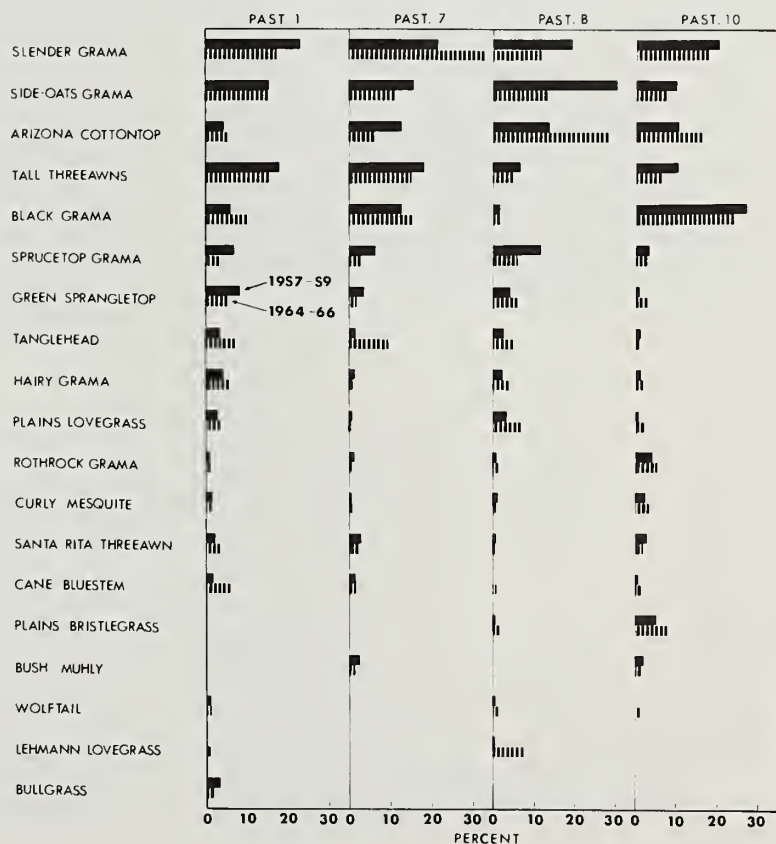
Three to five species each contributed over 10 percent of the herbage and together produced 50 to 80 percent of the total. Four to eight other species contributed between 2 and 10 percent each, and the remaining 8 to 10 species contributed less than 2 percent each. Considering all four pastures, the dominant species were: slender grama, side-oats grama, tall threeawns, Arizona cottontop, and black grama. These five species, on the average, produced from 64 to 75 percent of the perennial grass herbage.

Relative amounts of herbage produced by species that contributed more than 1 percent of the total either for the first or last 3 years of the study period are shown in figure 5. For the five major species, standard errors for the means (fig. 5) are mostly between 20 and 50 percent of the means. Standard errors of the less common species in some cases exceed the means.

In general, the composition of pastures 1 and 7 was similar, with the same three major perennial grasses (slender grama, side-oats grama, and tall threeawns). In pasture 8, side-oats grama and Arizona cottontop were the most productive species in the 1957-59 and 1964-66 periods, respectively. In pasture 10,

Figure 5.—

Percentages of perennial grass herbage produced by individual species during the first 3 (1957-59) and the last 3 (1964-66) years of the study.



black grama was the most productive species throughout the study period. In each pasture, the most productive species in 1957-59 were nearly always the most productive in 1964-66, and in about the same order.

A few large changes in relative production were recorded. Among the major species, production of sprucetop grama decreased nearly 60 percent between the first and last 3-year periods. Among the minor species, tanglehead nearly tripled its production, and Lehmann lovegrass (an introduced species) increased from a four-pasture average of less than 1 lb/acre to over 7 lb/acre. The large relative increase in lovegrass was due mainly to an increase from 1.6 lb/acre in 1957-59 to 28.6 lb/acre in 1964/66 in pasture 8, as the grass spread from seeded areas onto adjacent native range.

Perennial Grass Basal Intercept

Basal intercept of perennial grasses is a measure of basal ground cover. For the 10-year study period, perennial grass basal intercept averaged from 1.50 to 2.02 percent for the four pastures. Intercept fluctuated less from year to year than did production, and measured 2.5 to 3.5 times as much in the highest year as in the lowest.

Basal intercept increased less than did production. Three-year moving averages show that intercept increased 40.2 percent on the M-K pastures relative to that on the M-A pastures between 1957-59 and 1964-66 (fig. 6).

Contributions by individual species to perennial grass basal intercept were somewhat different from their relative contributions to

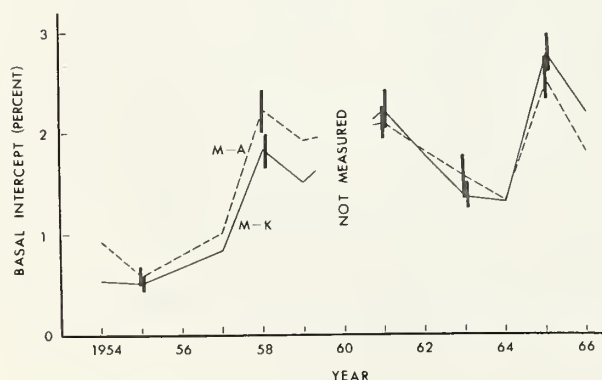


Figure 6.—Basal intercepts of perennial grasses for mesquite-killed (M-K) and mesquite-alive (M-A) pastures for the period of record \pm one standard error for selected years.

herbage production. As with production (fig. 5), however, the same five species were dominant (fig. 7), comprising from 62 percent to 70 percent of total perennial grass intercept.

Low-growing species produced less herbage per unit of basal intercept than the taller growing species. Table 3 shows average production (lb/acre) and average productivity per unit of basal intercept for the 17 most common species.

Table 3.—Average production and average productivity per unit of basal intercept for the 17 most common species on the four study pastures

Species	Average production	Productivity index ¹
- - Lb/acre - -		
Curly-mesquite	5.7	0.93
Sprucetop grama	22.0	1.10
Santa Rita threeawn	8.5	1.66
Hairy grama	10.8	1.67
Slender grama ²	85.7	1.92
Side-oats grama ²	58.9	2.25
Black grama ²	52.4	2.62
Rothrock grama	7.2	2.95
Tall threeawns ²	55.7	3.26
Arizona cottontop ²	63.0	3.72
Plains lovegrass	9.3	4.03
Lehmann lovegrass	3.4	4.45
Bush muhly	4.0	5.27
Green sprangletop	21.2	6.95
Tanglehead	16.1	8.24
Plains bristlegrass	7.2	8.27
Cane bluestem	8.9	8.60

¹Weight of herbage per acre per 0.01 percent of basal intercept.

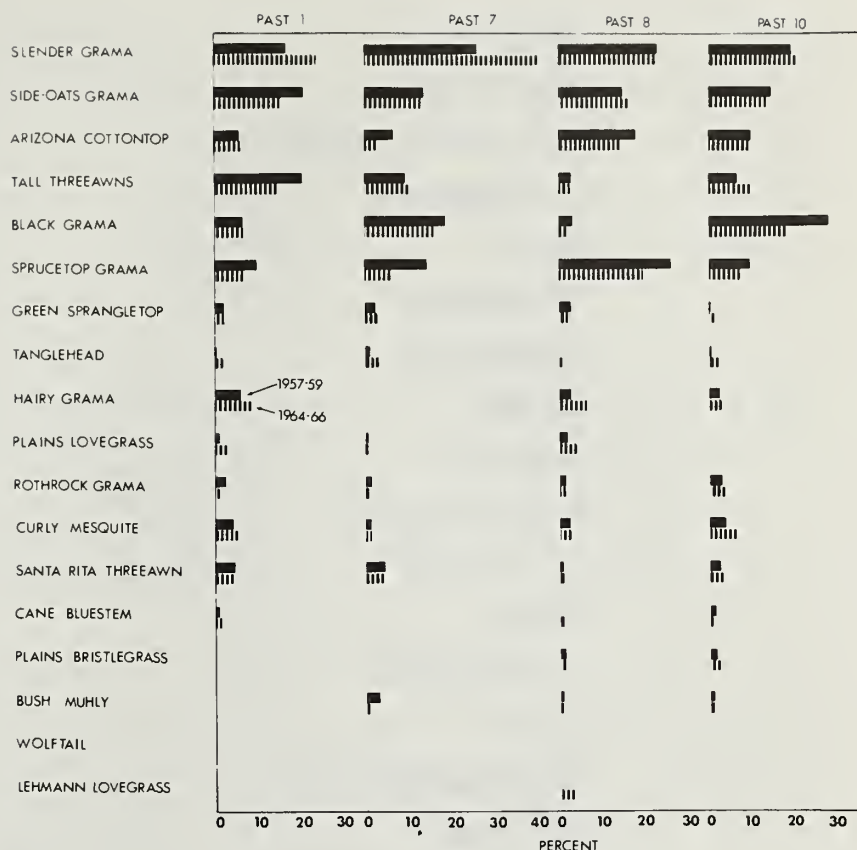
²Major species.

Thus curly-mesquite, Santa Rita threeawn, and the lower growing gramas produced the smallest amounts of herbage per unit of basal intercept, and the tall grasses—cane bluestem, plains bristlegrass, and tanglehead—produced the most. The five major species were intermediate in productivity. Standard errors of the productivity indexes varied from about 10 percent of the mean for high-producing species to 20-25 percent for low-yielding species.

Year-to-year variability (in terms of coefficient of variation, CV) averaged lower for the major species than for the minor species for both production and intercept. The important implication is that herbage yields of

Figure 7.—

Average percent of total perennial grass intercept contributed by each species during the first and last 3 years (1957-59 and 1964-66) of the study.



the major species are more dependable than those of the minor species:

	Coefficient of variation	
	Production	Intercept
	(Percent)	
Five major species	51	38
Seven minor species	64	75

Utilization of Perennial Grasses

Utilization of perennial grass herbage for the 1954-66 period of record on the four pastures varied from 29 percent to 65 percent; and was higher in dry years than in wet years (fig. 8). During the 3 years before the start of the study (1954-56) utilization in the four pastures averaged 55 percent; for the 10-year study period, use averaged between 35 percent and 44 percent, reasonably close to the desired 40 percent.

Utilization of individual species varied widely (fig. 9), and was related more strongly to preference by cattle than to relative availability on the range. Plains bristlegrass and Lehmann

lovegrass, two of the three most heavily utilized species were minor producers, but one of the three least utilized species, black grama, was a major producer.

Up to this point we have considered the relative importance of perennial grass species only in terms of herbage production (lb/acre)

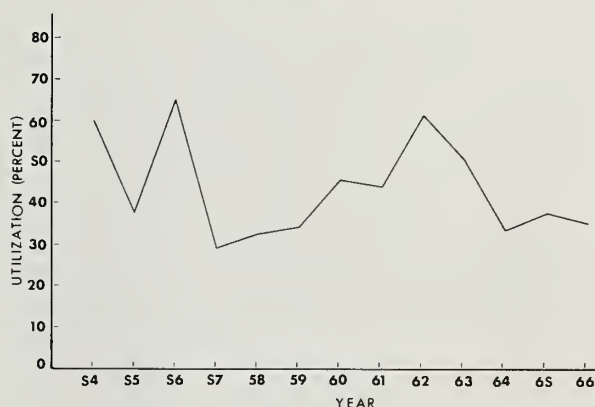


Figure 8.—Average utilization of perennial grass herbage (four-pasture average).

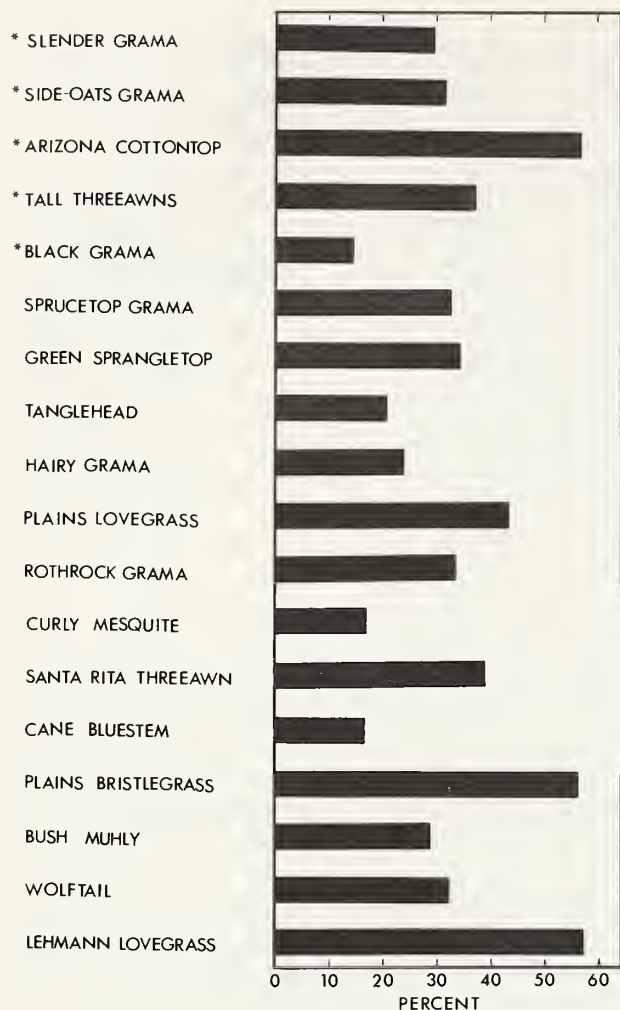


Figure 9.—Utilization of perennial grasses, first 3 and last 3 years averaged (five most productive species indicated by *).

and utilization (percent). Neither of these, alone, measures species importance as sources of forage. Pounds of grass consumed, however (a product of production times utilization), provides a useful basis for rating species.

On this basis, Arizona cottontop ranked first as a forage producer. It accounted for 22.4 percent of perennial grass consumed on the four pastures during the 10-year period (fig. 10). Slender grama ranked second; contributed 17.5 percent of the amount consumed. There was no correlation between production and consumption for the five major species.

For species of intermediate preference, consumption was in proportion to abundance, but for species near the high and low ends of the preference scale, consumption was dispro-

portionately above and below abundance, respectively. Three of the major species—slender grama, side-oats grama, and tall threeawn—contributed to forage consumption about in the same proportion as their contribution to production, and are considered to be of intermediate palatability. Arizona cottontop contributed much more to forage consumption than to production. Black grama's contribution to herbage grazed, however, was relatively small. Cottontop made up between 20 and 25 percent of the total herbage grazed, while comprising only 13 to 14 percent of the total herbage produced, indicating that this species was definitely preferred. Black grama, on the other hand, produced about 12 percent of the herbage but accounted for only 7 percent of the herbage grazed. Other species that were preferred include Santa Rita threeawn and plains bristlegrass. Other less preferred species include tanglehead, curly-mesquite, and cane bluestem.

Production of Annual Grasses

Annual grass production varied from essentially none in 1962, the driest year, to 425 lb/acre on the M-K pastures in 1959 (fig. 11). Annual grass production fluctuated much more than perennial grass production, reflecting the greater dependence of annual grass on short-term growing conditions. The management implication is that annual grasses are an undependable source of forage, particularly in the drier years when forage is most needed.

Three major factors affected annual grass production: (1) rainfall, (2) mesquite competition, and (3) perennial grass competition. Annual grass production was closely correlated ($P < 0.05$) with June-through-August rainfall, and even more closely with June-August rainfall for storms of 0.25 inch or more. Data for 9 of the 10 study years indicate that from 54 to 89 percent of the year-to-year variation in annual grass production was associated with changes in June-August rainfall.

Mesquite strongly affects annual grass production, although annual grass production varies widely from place to place over a relatively wide range of mesquite cover. Annual grass production can be essentially zero at any level of mesquite cover, but maximum annual grass production is limited by the amount of mesquite present, particularly where mesquite crown cover exceeds 10 or 12 percent. This inhibitory effect of mesquite is apparent in the regressions of annual grass production vs. June-August rainfall. Annual grass production increases least, per inch of increasing rainfall, where

Figure 10.—

Relative production compared to relative consumption of herbage for individual perennial grass species.

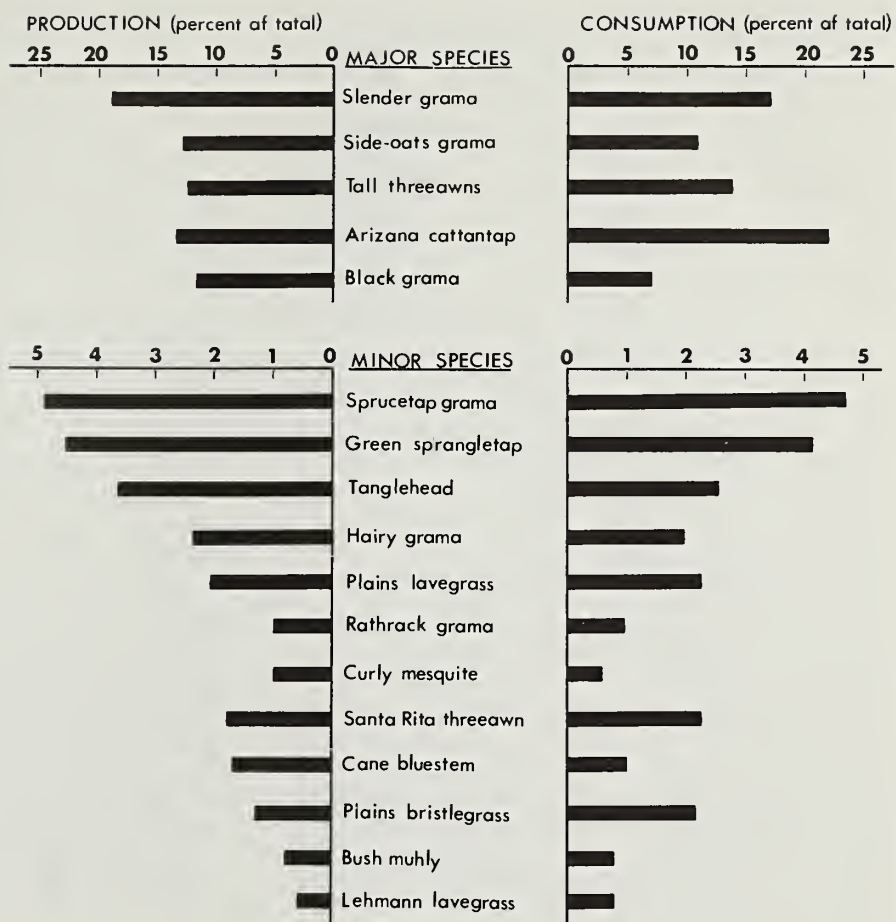
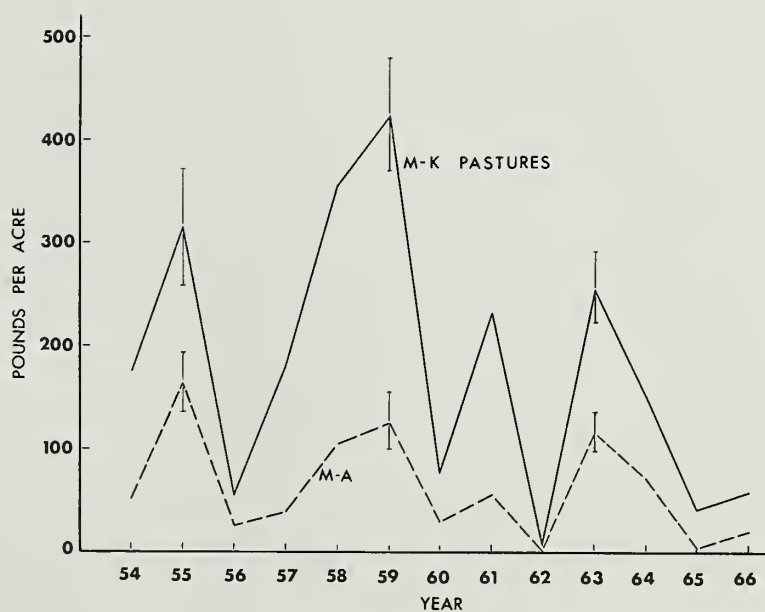


Figure 11.—

Yearly production of annual grasses in mesquite-killed (M-K) and mesquite-olive (M-A) pastures, with standard errors for selected years.



mesquite crown cover is most dense (pastures 8 and 10) and most where mesquite cover is least dense (pastures 1 and 7):

Pasture	Mesquite cover (Percent)	Increase per inch of precipitation (lb/acre)
1	0.46	29.2
7	.80	42.4
8	12.18	6.5
10	9.92	14.0

The influence of perennial grasses on annual grass production is difficult to isolate. Year-to-year changes in annual grass production tend to follow the same ups and downs as those for perennial grass production on any given transect, because they both are strongly affected by year-to-year changes in summer rainfall. Over a period of years, however, average annual grass production is negatively related to average perennial grass production, reflecting the strong competitive effect of perennial grasses on annual grasses.

This competitive effect can be illustrated by 8 of the 20 transects in pasture 1 (M-K). These transects are scattered over about 320 acres, but all are on smooth, gentle slopes of less than 10 percent, and all are on Comora sandy loam soil. They represent near-optimum conditions for grass production. Ten-year mean annual grass production varied between 75 and 506 lb/acre among transects, while mean perennial grass production varied between 292 and 336 lb/acre. In a strong negative linear relationship, 88 percent of the variation in annual grass production among the transects was accounted for by differences in perennial grass production. An increase in perennial grass production of 100 lb/acre resulted in a decrease of 75 lb/acre in annual grass production, with annual grass production reaching zero when perennial grass production was 940 lb/acre.

Changes in annual grass production were different in pasture 7, during the first half of the study period, than in the other three pastures. This difference is apparent in the ratios of annual grass production to perennial grass production (fig. 12). In general, on the four pastures, annual grass production varied from less than 10 percent as much as perennial grass production in dry years to nearly as much in some wet years. But in pasture 7, the ratio was 1.6 in 1957 and dropped sharply to less than 0.1 in 1962. Associated changes in perennial grass production show that perennial grass production increased 16 percent from the first to the last 3 years of the study period in pas-

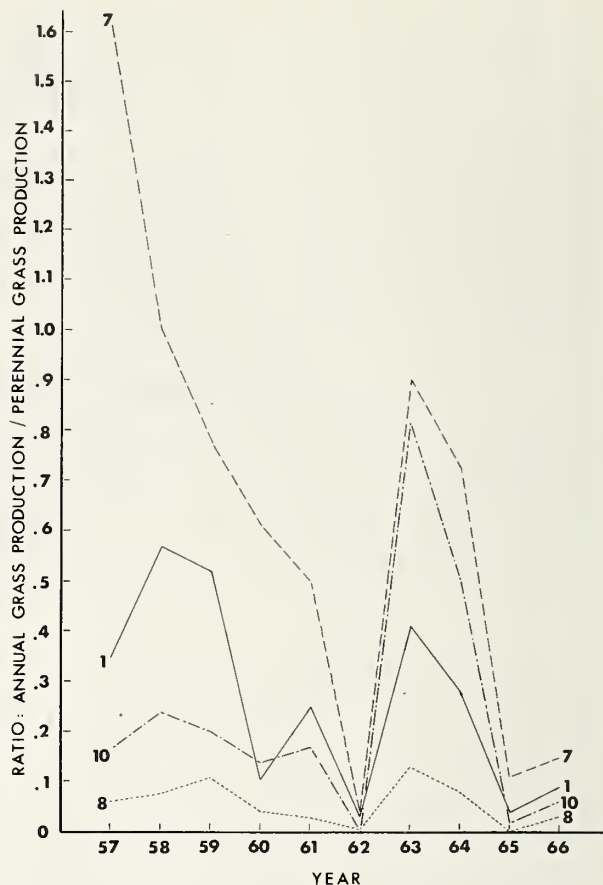


Figure 12.—Ratios of annual grass production to perennial grass production in the four study pastures.

ture 7 while in the other three pastures production decreased as much as 35 percent (see table 2). These data suggest that, during the early years of the study, pasture 7 was recovering from a much more depleted condition than were pastures 1, 8, and 10. As perennial grass production increased, with recovery from the depleted condition, annual grass production decreased. Pasture 1 exhibited this same pattern to a somewhat lesser degree.

The particular combinations of environmental conditions that affected soil moisture relations, and thus annual and perennial grass production, varied widely among transect locations. In general, as environmental conditions became less favorable for grass growth (steeper slopes, shallower or rockier soils, more shrub competition, etc.) the competitive advantage of perennial over annual grasses increased, and relative annual grass production decreased.

Tree and Shrub Cover

Mesquite

Mesquite crown cover was measured by two means: (1) intercept of crowns on twenty 100-ft line transects in each pasture, measured annually, and (2) crown cover of all trees on twenty 100-ft by 200-ft plots in each pasture, measured in 1957 and 1966.

The intercept data indicate little change in mesquite crown cover during the study period. In the two M-K pastures (1 and 7), crown cover did not exceed 0.55 percent during the first 9 years of the study period; in the 10th year, however, it averaged 1.59 percent and 1.43 percent, respectively. In the two M-A pastures (8 and 10) mesquite intercept averaged 7.30 percent and 3.14 percent, respectively, for the 10-year period, and showed no real increasing trend.

Crown-cover measurements based on crown diameters of all mesquites on the 100- by 200-ft plots revealed a somewhat different picture. In 1957, mesquite crown cover in pasture 10 was one-third less than in pasture 8, but by 1966 differences were relatively small (table 4).

The crown-cover measurements probably portray changes in mesquite crown cover more accurately than do the intercept measurements because they constitute a much larger sample.

Other Shrubs

Most of the tree-shrub cover was contributed by species other than mesquite. Between 15 and 19 "other" shrubby species were recorded on the line transects in each pasture. Of these, four contributed 76 to 87 percent of the total of

other-shrub intercept. False-mesquite ranked first among all shrubs, making up from 23 to 41 percent of total shrub intercept (including mesquite). Velvetpod mimosa ranked second among other shrubs, and was one of the four dominants in three pastures. Six other species were dominants in one or more of the four pastures.

Mesquite comprised 32 and 38 percent of total tree-shrub crown intercept on mesquite-alive pastures, but less than 2 percent on the mesquite-killed pastures (table 4).

Total tree-shrub crown cover was relatively high in 1959, 1964, and 1966, and low in 1961 and 1965 (fig. 13). In contrast to the relative stability of mesquite crown cover, intercepts of other shrubs varied more widely with year-to-year changes in growing conditions (table 4).

Vegetation-Precipitation Relations

Perennial grass plants grow and develop in two major phases: (1) enlargement of basal buds preparatory to shoot growth; (2) production of herbage by elongation, branching, and leaf development on the shoots. Each of these phases depends on precipitation at different periods of the year. The enlargement of basal buds depends primarily on late-summer rainfall. The enlarged buds then sprout the following spring or summer. Production of perennial grass foliage, therefore, depends partly on current summer rainfall and partly on that received during the previous summer.

Perennial Grass Production

Simple correlations between perennial grass production and rainfall show that, of the 4

Table 4.--Crown-cover measurements of mesquites, 1957 and 1966, and 10-year means of intercept measurements, on Mesquite-Killed and Mesquite-Alive pastures

Treatment and pasture	Crown cover (with standard errors)		10-year means of intercept		
	1957	1966	Mesquite	Other shrubs	Total
	- - Percent - -		- - - - ft/100-ft transect - - - -		
MESQUITE-KILLED:					
Pasture 1	0.53 ± 0.35	0.38 ± 0.11	0.16 ± 0.08	13.91 ± 0.96	14.07 ± 0.96
Pasture 7	1.15 ± .36	.45 ± .10	.05 ± .02	7.18 ± .62	7.23 ± .62
MESQUITE-ALIVE:					
Pasture 8	11.04 ± 2.16	13.31 ± 2.45	7.30 ± .54	11.44 ± .69	18.74 ± .84
Pasture 10	7.17 ± 1.31	12.67 ± 2.03	3.14 ± .45	7.15 ± .35	10.29 ± .58

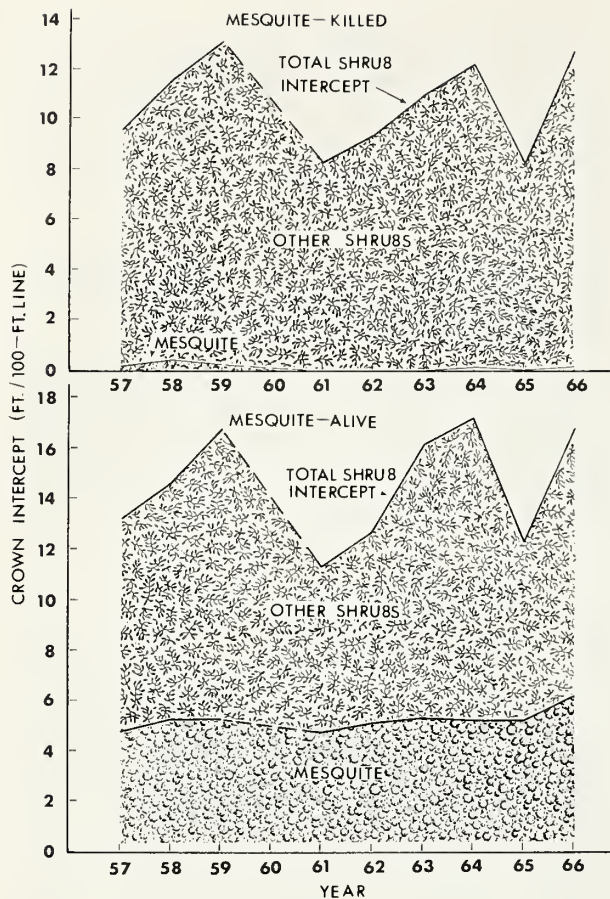


Figure 13.—Comparison of crown intercept of mesquite and other shrubs in mesquite-killed and mesquite-olive pastures.

summer months, rainfall in August is most highly correlated with grass production for the current summer (r 's=0.63 to 0.79 for the four study pastures). Rainfall for the June-August period is next most highly correlated. Correlations between the previous summer's June-September rainfall and current summer's grass production are low (0.22 to 0.28). However, the interaction rainfall term, obtained by multiplying previous June-September rainfall by current August rainfall (PJS x CAug, subject to an imposed maximum of 90.0 for the interaction product), yields much higher correlation coefficients (0.80 to 0.95) than either one alone.

Including all three of these relevant independent variables (CAug, PJS, and CAug x PJS) in a multiple regression equation is no improvement over the interaction rainfall term alone. It is clear that the effectiveness of a given amount of rainfall this summer is strongly affected by the amount of rainfall received last summer.

Regression equations indicate that perennial grass production in pastures 7, 8, and 10 responded in a similar manner to interaction rainfall, increasing from 8.3 to 9.2 lb/acre for each unit of increase in the interaction product (fig. 14). In pasture 1, because grass production was much higher for lower values of the interaction product, the increase in production was much smaller (5.5 lb/acre) for each additional interaction unit.

The influence of many other rainfall components on perennial grass production was also investigated. These components include various expressions of winter precipitation, alone and in combination with summer rainfall, as well as expressions involving size and spacing of storms. No improvement was obtained from these variables.

Low winter precipitation almost never limits perennial grass production the following summer, and high winter precipitation seldom increases summer grass production in the semi-desert Southwest. The lack of correlation between winter precipitation and perennial grass production the following summer is due to: (1) the grasses are warm-season grasses, in which most of the development taking place within the grass plant during winter consists of physiological changes rather than the production of herbage, requiring little water, and (2) there is essentially no carryover of available soil moisture from spring to summer.

The five major perennial grass species (and "others" grouped) generally responded to the same precipitation components as the total,

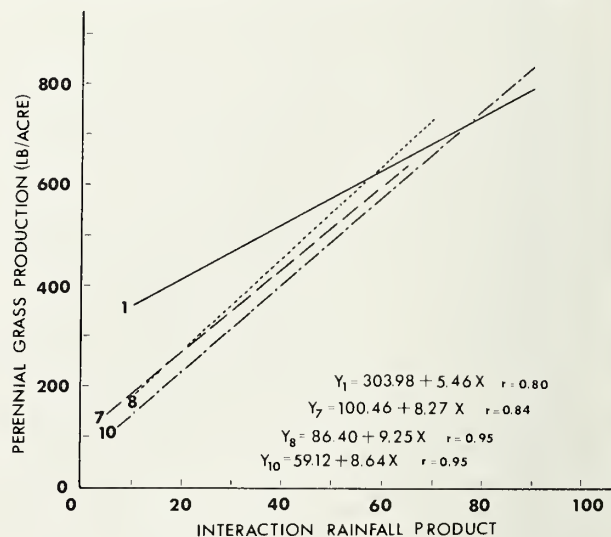


Figure 14.—Relation between perennial grass production and interaction rainfall product (product of last summer's June-September rainfall times rainfall for current August; ≤ 90.0).

although most correlation coefficients were somewhat lower.

Perennial Grass Basal Intercept

Changes in basal intercept are the direct result of the enlargement of basal buds. Buds usually enlarge in the early fall after herbage growth has been completed. The number and size of buds that develop during this period depend to some extent on the availability of soil moisture, which in turn depends on precipitation. Correlation coefficients relating September and October precipitation to perennial grass basal intercept measured the following summer are mostly between 0.66 and 0.82. The dependence on September and October rainfall is not strong, primarily because unusual precipitation events that wet the soil deeply at other seasons of the year can modify the typical time sequence of bud development. For example, unusually high winter-spring precipitation will activate additional buds in the spring growing period. And, unusually high rainfall during the summer growing period can also stimulate dormant buds to enlarge and sprout. Still, the size and productivity of the grass "factory" is dependent largely on the number and vigor of buds activated during the fall and winter.

Factors Affecting Utilization of Perennial Grasses

The grazing objective was to utilize 40 percent of the perennial grass available between the time of the forage survey in September and the following June 30. Year-to-year variations in percent use were associated negatively with the amount of perennial grass available per animal and to a lesser extent with the amount of perennial grass produced. These variables explain one-fourth to three-fourths of the year-to-year variation in percent use. Actual use seldom was exactly 40 percent, but the 10-year means were within about 10 percent of that objective.

Before considering utilization further, we should point out that the ungrazed-plant method of measuring utilization distorts the true percent use at the extremes. For example, a transect showing up to 7 percent of the plants grazed is recorded as having 0 percent use. Also, the maximum use that can be computed with the formula, even when 100 percent of the plants have been grazed, is 80 percent.

Percent use varied widely among the 20 transect locations in each pasture, and these differences among transects tended to remain

more or less fixed year after year. Three-year averages of use during the first and last 3-year periods varied from 26.3 percent to 43.4 percent, but use on individual transects varied from 0 to 71.4 percent.

The average degree of use of perennial grasses at any given location was affected by several factors, including:

1. Species palatability and composition
2. Distance to water
3. Slope of the ground
4. Rate of stocking of the pasture relative to the amount of forage available.
5. Distance to a salt ground.

Species Palatability and Composition

The most influential factor affecting percent use at a given location was the relative palatability of the forage. Palatability, as used here, refers to the degree of utilization of a particular perennial grass species under conditions of adequate forage and free choice. The palatability values were based on means of the first 3 and last 3 years only. The highest average pasture use was 43 percent. Because scarcity of a given species might not allow true "free choice" by a grazing animal, a transect was included for a given species only if that species contributed 10 percent or more of total perennial grass production.

Palatability ratings varied among the 4 pastures and 20 species from 0 to 73 percent (table 5). For the 15 minor species, 4-pasture palatability ratings varied from 0 percent for bullgrass and spike pappusgrass to 62 percent for plains bristlegrass. Among the five major species, mean palatability varied from 12 percent for black grama to 57 percent for Arizona cottontop.

Differences in palatability among species were most apparent in wet years when abundant forage permitted cattle their freest choice. During drier years, as the more palatable species became fully utilized, use of less palatable species increased. The most palatable species were grazed heavily in both situations. For example, use of Arizona cottontop, the most palatable major species, averaged only 9 percent higher in a dry year (7.5 inches summer rainfall) than in a wet year (12.5 inches summer rainfall). Use of black grama, however, the least palatable major species, averaged 30 percent higher ($r=-0.80^{**}$) in the dry than in the wet year. Thus cattle grazed black grama only slightly when more palatable forage was readily available.

The distortion of free-access preferences by heavy use was evaluated by plotting species

Table 5.--Relative frequency and palatability ratings, by pastures, of perennial grasses ranking among three most productive species at individual transect locations; means of two 3-year periods, 1957-59 and 1964-66 (ratings in parentheses are based on less than four transects in a single 3-year period)

Perennial grasses	Frequency	Palatability rating on pastures--				Mean
		Mesquite-Killed		Mesquite-Alive		
		1	7	8	10	
<i>Percent</i>						
MAJOR SPECIES:						
Slender grama	100	28	37	29	30	31
Side-oats grama	69	21	37	23	35	29
Arizona cottontop	60	66	43	64	56	57
Tall threeawns	62	37	38	47	32	38
Black grama	49	10	15	(12)	12	12
MINOR SPECIES:						
Sprucetop grama	26	24	46	30	38	34
Green sprangletop	12	26	(62)	30	51	42
Tanglehead	13	(14)	32	(23)	(28)	24
Hairy grama	15	26	(73)	(16)	(13)	32
Plains lovegrass	13	31		40		36
Rothrock grama	10		(48)	42	37	42
Curly-mesquite	6	(20)	8	(0)	(28)	14
Santa Rita threeawn	11	(61)	51	(30)	(10)	38
Cane bluestem	8	8	(T)		(10)	6
Plains bristlegrass	10			62	61	62
Bush muhly	5		(51)		(44)	48
Arizona muhly	2			(38)		38
Lehmann lovegrass	6	(65)		47		56
Bullgrass	6	0				0
Spike pappusgrass	1				(0)	0

use over transect use for transects on which each species contributed 10 percent or more of total perennial grass production. Species use for the five major species, when transect use was 10 percent, varied from 0 for black grama to 35.6 percent for Arizona cottontop (fig. 15). These use values were strongly correlated with the palatabilities shown in table 5. At 80 percent transect use, however, even the less palatable species were heavily used (68 to 80 percent) and species use values were not significantly correlated with species palatability.

Correlations for the regressions in figure 15 varied from 0.75 to 0.90. All were highly significant. The regressions differed significantly, both among levels and among slopes. The differences in levels are, of course, due to differences in palatability. The differences in slopes are related more to availability than to palatability in that cattle turned increasingly to less palatable species as the more palatable species were grazed off. The practical implication is that the less palatable species cannot be fully used unless overall use is heavy, which should happen only in dry years if at all.

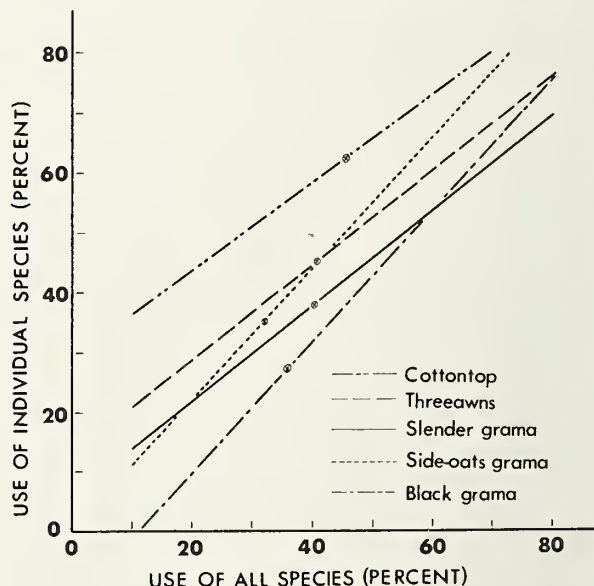


Figure 15.—Average use of individual major species relative to average use for all species.

To evaluate the effect of forage palatability on utilization at each of the 80 transects, a palatability-composition (P-C) index was derived from 3-year averages (1957-59 and 1964-66) of production and use of the three highest yielding perennial grasses on the transect, as follows:

Highest yielding grasses	Percent of production/100	Percent use/100	Product
1st	0.46	0.45	0.2070
2d	.27	.37	.0999
3d	.17	.36	.0612
P-C index			.3681

These palatability-composition indexes varied from 0.0408 to 0.6867. In simple linear regression, they appeared to account for from 61 to 94 percent of the variation in use among transects in a given pasture.

Distance to Water, and Topographic Influences

These variables interact strongly in their effect on forage use. The relationship between distance to water and percent use illustrates the overriding influence of local topographic and vegetation differences. For the four pastures together, the average effect of distance was to decrease use 0.5 percent for each 0.1 mile. Minimum use was about 10 percent for some transects throughout the range of distances, however, and the maximum effect of distance was to decrease use about 3.5 percent for each 0.1 mile from water (fig. 16).

The effect of steepness of slope on herbage use is confounded in part by differences in the preference of certain grass species for slopes of varying steepness. Of the 14 most productive species, 6 were most productive on slopes of 10 percent or less, 4 on slopes over 30 percent, and the other 4 produced about equally on all slopes. Of the species that preferred flatter slopes, four (Santa Rita threeawn, Lehmann lovegrass, plains bristlegrass, and Arizona cottontop) were only rarely found on slopes exceeding 15 percent. The other two (tall threeawns and hairy grama) occurred on slopes over 30 percent, but less frequently.

Of the four species that preferred steep slopes, three (cane bluestem, plains lovegrass, and green sprangletop) showed a strong preference (over 60 percent of their occurrence was on slopes over 30 percent). Side-oats grama was found also on the flattest slopes, but less frequently. Distribution of the four intermediate species (sprucetop, black and slender gramas,

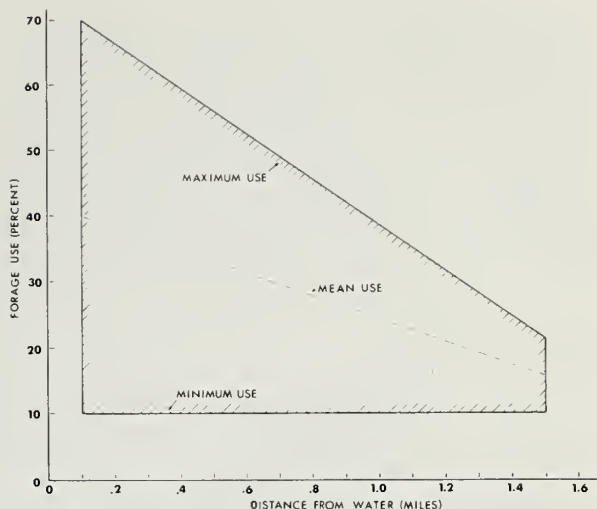


Figure 16.—Relationship between degree of forage use and distance from water.

and tanglehead) was apparently independent of slope.

Distance and slope, together with species palatability and composition, were sufficiently consistent in their effects on utilization to be combined in a multiple regression analysis. On an overall basis, using the 10-year mean percent use for each of the 80 transects as the dependent variable, the effects of palatability and composition, slope of the ground at the transect location, and distance to water are given by the equation:

$$\begin{aligned} \text{Percent use} = & 27.40 + 64.84 (\text{P-C index}) \\ & - 0.17 (\text{Slope}) - 4.94 (\text{Distance}) \\ & (\text{overall } F=90.92^{**}). \end{aligned}$$

Distances and slopes were in terms of miles (range: 0.1 to 1.5) and percent (range: 3 to 58), respectively.

According to this equation, mean use increased 6.5 percent for each increase of 0.10 point in the P-C index, decreased 1.7 percent for each 10 percent increase in slope, and decreased 0.5 percent for each increase of 0.1 mile from water. These three variables accounted for 78 percent of the variability in mean use among the 80 transects. On the individual pastures, with less diverse topography and vegetation, they explain from 78 to 93 percent of the variability in mean use among the 20 transects. In most cases, differences in the P-C index were responsible for most of the differences in percent use among transects.

The multiple regression also revealed a highly significant negative correlation between percent slope and the P-C index. This suggests that the more palatable species favor the flatter slopes, and the less palatable species either

favor steep slopes, or in some cases are about equally common on all slopes. The significant negative relationship between percent use and slope, previously presented, must therefore be due to a combination of less palatable species on the steeper slopes and a preference by cattle to graze flatter slopes. The fact that the species on the steep slopes are, on the average, less palatable, may be one reason cattle prefer to graze flatter slopes.

Rate of Stocking

For any given forage crop and period of use, increased stocking will increase utilization. In this study, however, stocking was adjusted each year so as to achieve about 40 percent use of the perennial grass herbage. Differences in percent use from year to year tended to be correlated negatively with stocking rates.

Effect of Salt Placement on Utilization Patterns

The establishment of a new salt ground in 1961 in the northwest part of pasture 10, about 1.5 miles from water, provided an opportunity to evaluate the effect of salt on the grazing patterns of cattle. Mean use for the pasture as a whole was 7.5 percent higher in 1965-67 than in 1957-60, but mean use of the transects over 1 mile from water, in the northwest part of the pasture within 0.5 mile of the new salt ground, was 16.5 percent greater (difference significant at $P < 0.01$). Meanwhile, the six transects in the northeast part of the pasture, 0.8 to 0.9 mile from water and 0.8 to 1.0 mile from the new salt ground, showed 5.5 percent decrease in use. This new salt ground, therefore, resulted in a significant increase in utilization of nearby areas at the expense of areas farther from salt.

Influence of Degree of Use on Productivity of Perennial Grasses

If the productive capacity of a range is to be maintained, management practices must permit the individual grass plants to remain healthy and vigorous. Since productivity is one of the best measures of range condition, we studied the productivities of the major species, and total productivity on transects used at different levels during the 10-year study. We used a trend analysis of variance of repeated measures, using the 10 years of production records, with the 20 transects in each pasture segregated into

4 groups of 5 transects each, on the basis of 10-year mean use. Mean use for Group 1 averaged from 21 percent to 28 percent among the four pastures, with Groups 2, 3, and 4 varying from 31 to 41 percent, 40 to 48 percent, and 52 to 59 percent, respectively.

The analysis revealed significant ($P = < 0.05$) differences in total perennial grass production among groups, and, more importantly, a highly significant year \times group interaction, indicating that production on transects used at different levels did not react the same in different years. This kind of result would ordinarily be assumed to represent changing trends with time among the four groups. In this instance, however, the differences in reaction among groups was not so much a time-trend reaction as a reaction to differences in growing conditions in certain years. Thus, mean production values for the four groups were clustered closely in the first and last years of the study (1957 and 1966 in fig. 17A). In wet years, however, particularly those following very dry years (such as 1957, 1960, and 1962), large differences in production were apparent among use groups. Group 1 transects made the most pronounced gain in production, Groups 2 and 3 intermediate, and Group 4 the least. The logical inference, in terms of the growth and behavior of the grass plants, is that increasing levels of use, and particularly the heavy use in the fourth group, prevented the plants from maintaining optimum vigor. Therefore they were not able to respond fully to high rainfall for at least 2 years following a very dry year. By 1966, following three favorable growing seasons, Group 4 transects had apparently recovered from the 1962 drought. This finding has important management implications in that recovery following drought will be much lower and slower on ranges that are consistently utilized heavily than on moderately used ranges.

Similar analyses for the five major species and for all other perennial grasses, grouped, indicated that differences among species probably were related to inherent differences in tolerance to heavy use. "Other" perennial grasses, side-oats grama, and black grama exhibited the same fluctuation pattern as for all perennial grasses. Side-oats grama and "other" perennial grasses in particular, exhibited a very pronounced difference in production in the wet years between Use Groups 1 and 4, at the upper and lower extremes, respectively (fig. 17B).

The response of the "other" perennial grasses is of particular importance, in that these species as a group made up 30 percent of the total perennial grass production during the 10-year study—more than any single species

—and because they are especially sensitive to level of use.

Arizona cottontop, on the other hand, showed the largest wet-year gains on Group 4 (heavily used) transects and the lowest gains on Group 1 transects (fig. 17C). We interpret

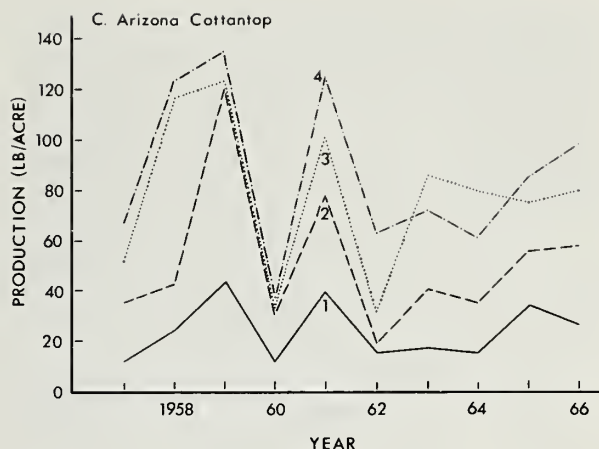
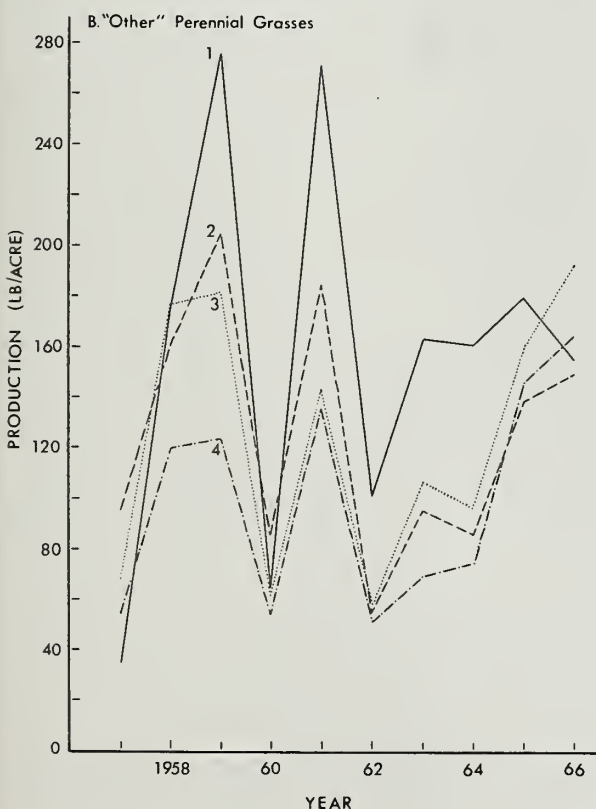
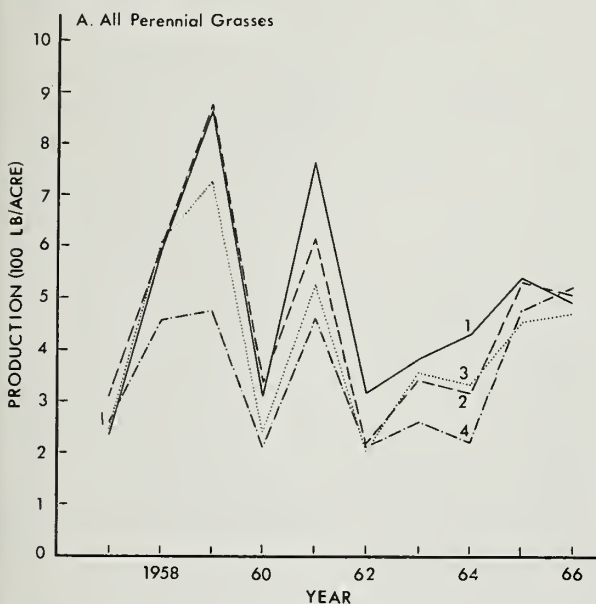


Figure 17.—Perennial grass production on transects used at different levels for the period 1957-66. Mean 10-year use for Groups 1, 2, 3, and 4 were 25, 37, 45, and 56 percent, respectively. A, All perennial grasses; B, "Other" perennial grasses; C, Arizona cottontop.

this response to mean that (1) cottontop can tolerate considerably heavier use than the other species, and (2) cottontop growth is stimulated by grazing. The nature of this growth stimulation undoubtedly is related to the fact that cottontop shoots contain many basal and culm buds (Cable 1971) which sprout easily and quickly when the terminal growing point is removed. With successively lower levels of use, fewer terminal growing points are removed and there is less stimulation to sprouting.

The response of slender grama differed from both of the previous types in that the major increases in wet-year production were on Groups 2 and 3 transects, with less response on transects in Groups 1 and 4.

Stocking Rates

Stocking rates were adjusted annually in the fall in response to changes in perennial grass production. Changes were not in direct proportion, however, because production varied more widely from year to year than cattle numbers could practicably be changed. Ratios of highest to lowest perennial grass production, for example, varied from 3:1 to 5:1 among pastures, while those for stocking varied from 2:1 to 3:1.

Ten-year average stocking on these pastures (for 40 percent use) varied from 22 to 38 head of cattle (15 to 32 head/section yearlong). Stocking rates for individual years were estimated by a regression formula derived from past

records of annual and perennial grass production, and stocking adjusted to 40 percent use. These stocking estimates were strongly correlated (r 's=0.79 to 0.93) with "backsight" estimates made at the end of each grazing year, of what the stocking rate should have been to obtain exactly 40 percent use. Standard errors of estimate varied between 3.3 and 7.3 head.

The regression formulas met the needs of the study very well, but they would not be useful for the average rancher who does not maintain records of forage production and stocking. The rancher needs an easier method. In an earlier section, a strong correlation between rainfall and perennial grass production was described. Since stocking depends on grass production and grass production depends on rainfall, a logical next step was to relate rainfall directly to stocking. To do this we used the product (Past June-September precipitation) x (Current August precipitation) as the independent variable and actual stocking adjusted to 40 percent utilization ("backsight stocking") as the dependent. These correlations of the "backsight" stocking rates for 40 percent use with the interaction rainfall products showed highly significant ($P = < 0.01$) relationships in all four pastures. From 73 to 94 percent of the year-to-year variation in stocking rates during 1957-66 would have been explained by changes in the rainfall product. Correlations were slightly higher (r 's=0.85 to 0.97) and standard errors of estimate were lower (2.8 to 5.7 head) than for the stocking estimates based on grass production.

Thus, on these four pastures with relatively good stands of grass, and with mesquite overstory on two of them, stocking rates to obtain 40 percent use of perennial grass could have been determined as well from rainfall records as from forage estimates. Good records of actual stocking and utilization are necessary in either case, but rainfall is easier and cheaper to measure than is grass production. Successful use of such a relationship for estimating stocking rates also depends on maintaining the range in good vigor so that the grasses can respond quickly to changes in rainfall, especially following drought years.

Influence of Soil Type on Grass Composition and Production

Three soil types predominate on the study pastures: Whitehouse, with clayey subsoils and well developed horizons; Comora, with sands or sandy loams in the subsoil and weak profile development; and Coronado, a shallow, stony,

and cobbly soil of the steeper slopes. Tumacacori soils, which are somewhat less coarse than Comora but otherwise similar, have been included with Comora. Surface textures of all soils are open, varying between loam and gravelly sandy loam. Thus the major differentiation among the three soils is in texture and depth of the subsoil. Of the 80 transects, 69 are on these three soils: 31 on Whitehouse, 23 on Comora (and Tumacacori), and 15 on Coronado.⁴

Fourteen of the twenty most common species of perennial grasses grew on all three soils, three grew on two of the three soils, and three species were restricted to a single soil type (table 6). Tall threeawns and slender grama, two of the five major perennial grasses in the study pastures, were also almost equally abundant on the three soils. Arizona cottontop showed strong adaptability to both the Whitehouse and Comora soils (slightly favoring the Comora), but dropped in ranking from third to tenth place on the Coronado soil. Side-oats grama, on the other hand, ranked fifth and fourth, respectively, on Whitehouse and Comora soil, but first on Coronado. Curly-mesquite and plains bristlegrass, which ranked eighth and eleventh, respectively, on Whitehouse soil, were not found on either of the other soils.

Table 6.--Relative productivity rankings of 20 perennial grasses on three soil types

Species	Whitehouse	Comora	Coronado
Tall threeawn	1	1	2
Slender grama	2	2	3
Arizona cottontop	3	3	10
Sprucetop grama	4	8	5
Side-oats grama	5	4	1
Black grama	6	5	9
Hairy grama	7	11	8
Curly-mesquite	8		
Green sprangletop	9	10	4
Spike pappusgrass	10	15	11
Plains bristlegrass	11		
Plains lovegrass	12	16	6
Bush muhly	13	13	
Tanglehead	14	6	14
Cane bluestem	15	14	7
Lehmann lovegrass	16	12	15
Santa Rita threeawn	17	7	
Rothrock grama	18	9	16
Arizona muhly	19		13
Bullgrass			12

⁴ Typed soil survey report dated July 31, 1967, on file at the Rocky Mountain Station's Research Work Unit, Tucson, Arizona.

Soil type affected production differently for annual and perennial grasses. Perennial grass production (10-year mean) varied within a range of 83 lb/acre, and differences among soils were not significant. Production of annual grasses, on the other hand, differed significantly among the three soil types, and also between M-K and M-A pastures:

Soils	Perennial grasses	Annual grasses
	(lb/acre)	
Whitehouse:		
M-K	412	120
M-A	441	37
Comora:		
M-K	457	277
M-A	495	115
Coronado:		
M-K	487	22
M-A	439	57

Cost-Benefit Evaluation of Mesquite Control

The economics of mesquite control cannot be precisely evaluated because of lack of beef production and other cost data for these pastures. However, an economic evaluation can be approximated on the basis of increased stocking rates resulting from mesquite control.

Stocking rates on the M-K pastures increased 0.15 animal-unit month/acre (AUM/acre) relative to those on the M-A pastures, between 1957-59 and 1964-66. The economic value of this increase can be evaluated on the same basis as an increase in grazing capacity of an existing ranch unit due to improved management practices (O'Connell and Boster 1974). Many of the increased costs associated with such increases in grazing capacity (property taxes, insurance, utilities, etc.) are less per increased AUM than for the previously existing AUM's. O'Connell and Boster estimated a net return, as of 1972, of \$5.82 per AUM from such range improvement practices. On this basis, the 0.15 AUM/acre resulting from mesquite control in this study would have a value of \$0.87/acre/year.

Actual costs of killing the mesquite in pastures 1 and 7 with diesel oil sprayed on individual stem bases were higher than would be incurred on an operational basis using the most effective herbicides available. Two treatments in successive years with 2,4,5-T, aerially applied, would cost about \$5.00 per acre, and provide about 90 percent release from mesquite competition. At this cost for mesquite control,

the increased income would recover the cost in about 6 years. Because such control treatments commonly remain effective for 15 to 20 years, the treatments would be economically justified.

Mesquite control also results in other tangible and intangible benefits. Increases in perennial grass cover reduce runoff. Sheet erosion decreases and gullies heal. Opening up the shrub canopy improves visibility and makes handling livestock easier. Tree shade for cattle from other tree species and surviving mesquite would still be available, however. And finally, treated areas, with relatively large expanses of open grassland with interspersed trees, can be more esthetically pleasing.

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COMMON AND SCIENTIFIC NAMES OF PLANTS MENTIONED

Annual Grasses

Needle grama	<i>Bouteloua aristidoides</i> (H.B.K.) Griseb.
Sixweeks threeawn	<i>Aristida adscensionis</i> L.

Perennial Grasses

Arizona cottontop	<i>Trichachne californica</i> (Benth.) Chase
Arizona muhly	<i>Muhlenbergia arizonica</i> Scribn.
Black grama	<i>Bouteloua eriopoda</i> Torr.
Bullgrass	<i>Muhlenbergia emersleyi</i> Vasey
Bush muhly	<i>Muhlenbergia porteri</i> Scribn.
Cane bluestem	<i>Andropogon barbinodis</i> Lag.
Curly-mesquite	<i>Hilaria belangeri</i> (Steud.) Nash
Green sprangletop	<i>Leptochloa dubia</i> (H.B.K.) Nees
Hairy grama	<i>Bouteloua hirsuta</i> Lag.
Lehmann lovegrass	<i>Eragrostis lehmanniana</i> Nees
Plains bristlegass	<i>Setaria macrostachya</i> H.B.K.
Plains lovegrass	<i>Eragrostis intermedia</i> Hitchc.
Rothrock grama	<i>Bouteloua rothrockii</i> Vasey
Santa Rita threeawn	<i>Aristida glabrata</i> (Vasey) Hitchc.
Side-oats grama	<i>Bouteloua curtipendula</i> (Michx.) Torr.
Slender grama	<i>B. filiformis</i> (Fourn.) Griffiths
Spike pappusgrass	<i>Enncapogon desvauxii</i> Beauv.
Sprucetop grama	<i>Bouteloua chondrosioides</i> (H.B.K.) Benth.
Tall threeawns	<i>Aristida hamulosa</i> Henr. and <i>A. ternipes</i> Cav.
Tanglehead	<i>Heteropogon contortus</i> (L.) Beauv.
Wolf tail (Texas timothy)	<i>Lycurus phleoides</i> H.B.K.

Trees and Shrubs

Burroweed	<i>Aplopappus tenuisectus</i> (Greene) Blake
Catclaw acacia	<i>Acacia greggii</i> A. Gray
Engelmann pricklypear	<i>Opuntia engelmannii</i> Salm-Dyck
False-mesquite	<i>Calliandra eriophylla</i> Benth.
Littleleaf krameria	<i>Krameria parvifolia</i> Benth.
Ocotillo	<i>Fouquieria splendens</i> Engelm.
Sacahuista	<i>Nolina microcarpa</i> S. Wats.
Velvet mesquite	<i>Prosopis juliflora</i> var. <i>velutina</i> (Woot.) Sarg.
Velvetpod mimosa	<i>Mimosa dysocarpa</i> Benth.
Wheeler sotol	<i>Dasyllirion wheeleri</i> S. Wats.
Wright buckwheat	<i>Eriogonum wrightii</i> Torr.

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1975. Vegetation responses to grazing, rainfall, site condition, and mesquite control on semidesert range. USDA For. Serv. Res. Pap. RM-149, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Changes in herbage production, basal intercept, and grazing use of perennial grasses, herbage production of annual grasses, and crown intercept of shrubs and trees were related to changes in rainfall, presence or absence of velvet mesquite, and to differences in soil, topography, and salting. Over a 10-yr period, mesquite control increased perennial grass production 52 percent. Perennial grass production was highly dependent on both last summer's and this summer's rainfall, indicating that 2 yrs are required for recovery from a 1-yr drought. Too heavy use greatly restricted production in wet years that followed dry years. Because of the strong relationship between rainfall and grass production, stocking rates could be estimated as accurately from rainfall as from grass production.

Keywords: Semidesert range, mesquite control, grass production, rainfall effects, grazing effects, site conditions.

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